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## **Maintenance and Drainage Guidance for the Scott Base Transition, Antarctica**

Sally Shoop, John Hills, and Julia Uberuaga

October 2014



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# **Maintenance and Drainage Guidance for the Scott Base Transition, Antarctica**

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## **Abstract**

The snow roads at McMurdo Station, Antarctica, are the primary transportation corridors for moving personnel and material to and from the airfields servicing intra- and intercontinental air traffic. The majority of the road system is made of snow overlying a snow and ice subsurface. However, at the Scott Base Transition (SBT), the aggregate road leading from Scott Base transitions from the land mass of Ross Island on to the ice shelf and becomes a full depth snow road. Because of the transition between materials, the topography of the area, and extensive use during the austral summer, the SBT is prone to problems unique to that portion of the McMurdo road system and requires specific maintenance activities to remain passable during periods of higher temperatures. The SBT area is divided into two subsections: the Land Transition, a soil- or aggregate-surfaced road underlain by permafrost, and the Ice Transition, a snow-surfaced road underlain by snow and ice. The two sections of the SBT need entirely different construction and maintenance techniques to maintain road surface conditions that will support vehicle traffic. This document provides a baseline guide for construction, maintenance, and repairs of the two distinctly different segments of the SBT.

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## Preface

This study was conducted for National Science Foundation (NSF), U.S. Antarctic Program, Division of Polar Programs (PLR), under Engineering for Polar Operations, Logistics, and Research (EPOLAR) EP-ANT-13-03, “Snow Roads and Transportation Monitoring and Guidance.” The technical monitor was George Blaisdell, Chief Program Manager, NSF-PLR, U.S. Antarctic Program.

The work was performed by Dr. Sally A. Shoop (Force Projection and Sustainment Branch, Dr. Edel Cortez, Chief), U.S. Army Engineer Research and Development Center (ERDC), Cold Regions Research and Engineering Laboratory (CRREL), and John Hills and Julia Uberuaga, Antarctic Support Contract (ASC). At the time of publication, Dr. Lindamae Peck was Acting Chief of the Research and Engineering Division at ERDC-CRREL. The Deputy Director of ERDC-CRREL was Dr. Lance Hansen, and the Director was Dr. Robert Davis.

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COL Jeffrey R. Eckstein was the Commander of ERDC, and Dr. Jeffery P. Holland was the Director.



## Acronyms and Abbreviations

AFD	Antarctic French Drain
ASC	Antarctic Support Contract
CRREL	U.S. Army Cold Regions Research and Engineering Laboratory
EPOLAR	Engineering for Polar Operations, Logistics and Research
ERDC	Engineer Research and Development Center
GPR	Ground-Penetrating Radar
HMW	High Molecular Weight
NSF	National Science Foundation
PLR	Division of Polar Programs
RPSC	Raytheon Polar Service Company
SBT	Scott Base Transition



# 1 Introduction

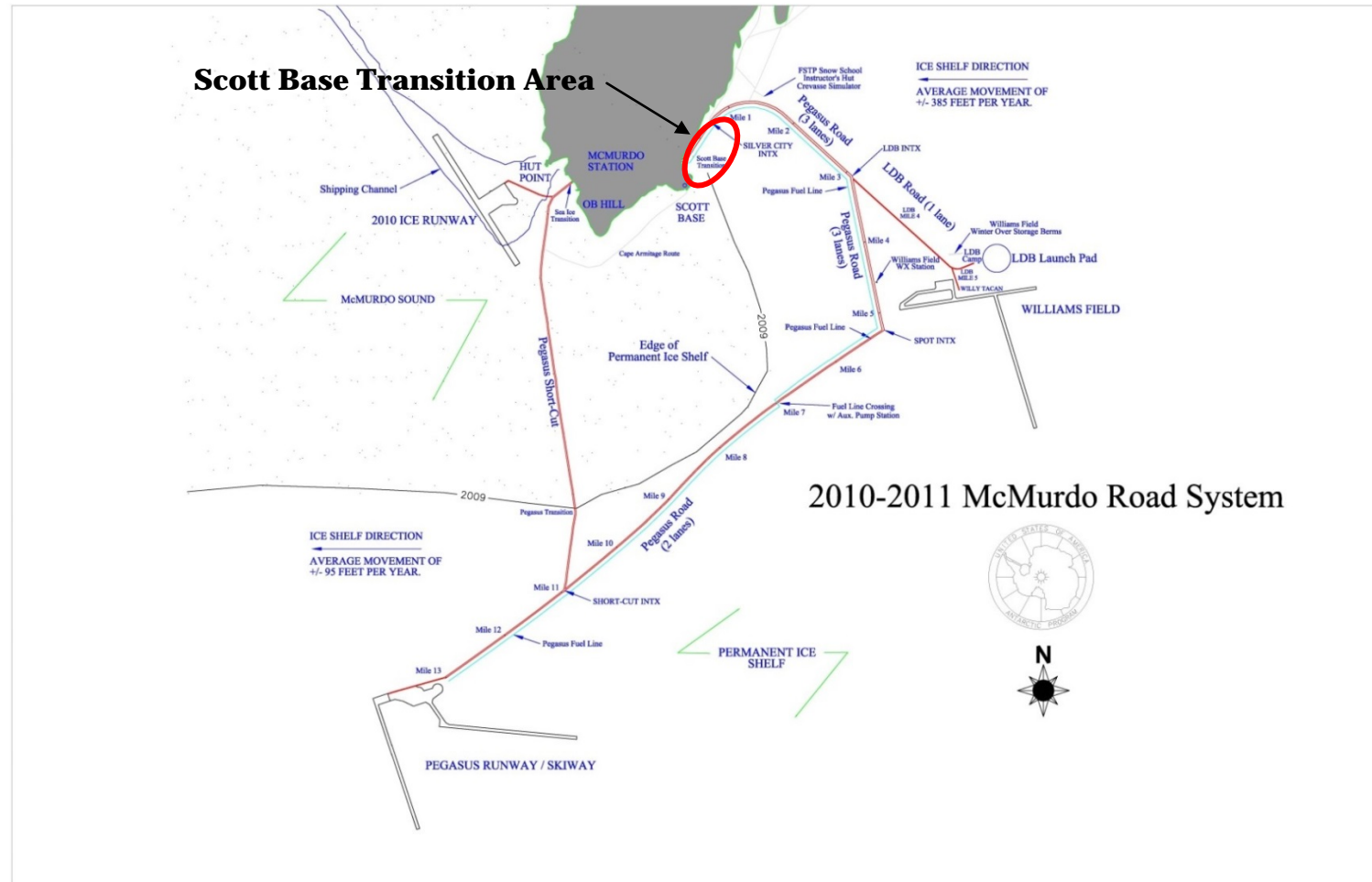
The snow roads at McMurdo Station, Antarctica, shown in Figure 1, are the primary transportation corridors for moving personnel and material to and from the airfields servicing intra- and intercontinental air traffic. The majority of the road system is made of snow overlying a snow and ice sub-surface. However, at the Scott Base Transition (SBT), the aggregate and soil road leading from Scott Base transitions from the permafrost, soil, and rock subbase of Ross Island on to the ice shelf and becomes a full depth snow road (Figure 1). Because of the transition between materials, the topography of the area, and extensive use during the summer, the SBT is prone to problems unique to that portion of the McMurdo road system and requires specific maintenance activities to remain passable during periods of higher temperatures. This document provides a baseline guide for construction, maintenance, and repairs of the two distinctly different segments of the SBT. This report serves as an accompaniment to Antarctic Support Contract (ASC) Manuals for construction and maintenance of the Scott Base Transition and the snow-road system in general (ASC 2014, forthcoming).

Fleet Operations is responsible for all construction, maintenance, and repairs to the road systems and land–ice transitions in the Ross Island area, including the SBT. However, all snow-road users are responsible for keeping their vehicles clean and driving responsibly to minimize impacts on the snow roads and transition areas.

## 1.1 Scott Base Transition

The SBT as we know it today was constructed in 1983. The current transition was constructed because the prior transition section was prone to major meltwater issues, cracks, and pressure ridges. The SBT area is divided into two subsections: the Land Transition, a soil- or aggregate-surfaced road underlain by permafrost (permanently frozen ground consisting of frozen soil and rock), and the Ice Transition, a snow-surfaced road underlain by snow and ice. These two sections of the SBT need entirely different construction and maintenance techniques to maintain road surface conditions to support vehicle traffic.

Figure 1. McMurdo road system map.



## 1.2 Seasonal maintenance

A unique aspect of the work at McMurdo Station, Antarctica, is the seasonal variation in activity level at the station. These changes in personnel levels and vehicle traffic volume affect road construction and maintenance in combination with the seasonal weather changes that affect snow and ice conditions. The peak activity level, in terms of scientific research and infrastructure projects, coincides with the austral summer, when peak temperatures and softening snow and ice conditions occur.

There are three seasons of work at McMurdo Station with regard to snow-road maintenance and construction:

- **Winter**—The Antarctic winter season runs from late February through mid-August and is a period of limited science activity. This results in less traffic during this time.
- **Winter Fly-In (Winfly)**—This is a six-week period beginning about 20 August and ending about 1 October. Historically, this is when crews arrive to prepare the infrastructure at McMurdo Station for the influx of scientists over the austral summer. This includes reopening station infrastructure and constructing the ice runway.
- **Main Body**—This period runs from 1 October through late February and is the austral summer season, bringing a mass influx of personnel and the bulk of construction and research activities. The latter half of this period is also the most critical and debilitating to the entire snow-road system but especially to the SBT area.

Later in this report, we will discuss these seasons in more detail with regard to the maintenance activities that take place during each season.

## **2 SBT Land Transition**

Vigilance and regular maintenance are critical to providing the SBT the best chance of remaining fully operational through the difficult last portion of Main Body. Year-to-year variances in ambient temperature, cloud cover, winter snow deposition, and melt impact the transition areas greatly. Issues that affect the Land Transition section are water runoff, subsurface melting, traffic load (vehicle count and weight), and working tidal cracks through the permafrost on the “land” side and the “snow” side of the SBT. For reference, Figure 2 provides a map showing the features of the SBT and the locations of mitigation structures used during 2010–2011.

The two main objectives of the maintenance of the SBT Land Transition are the following:

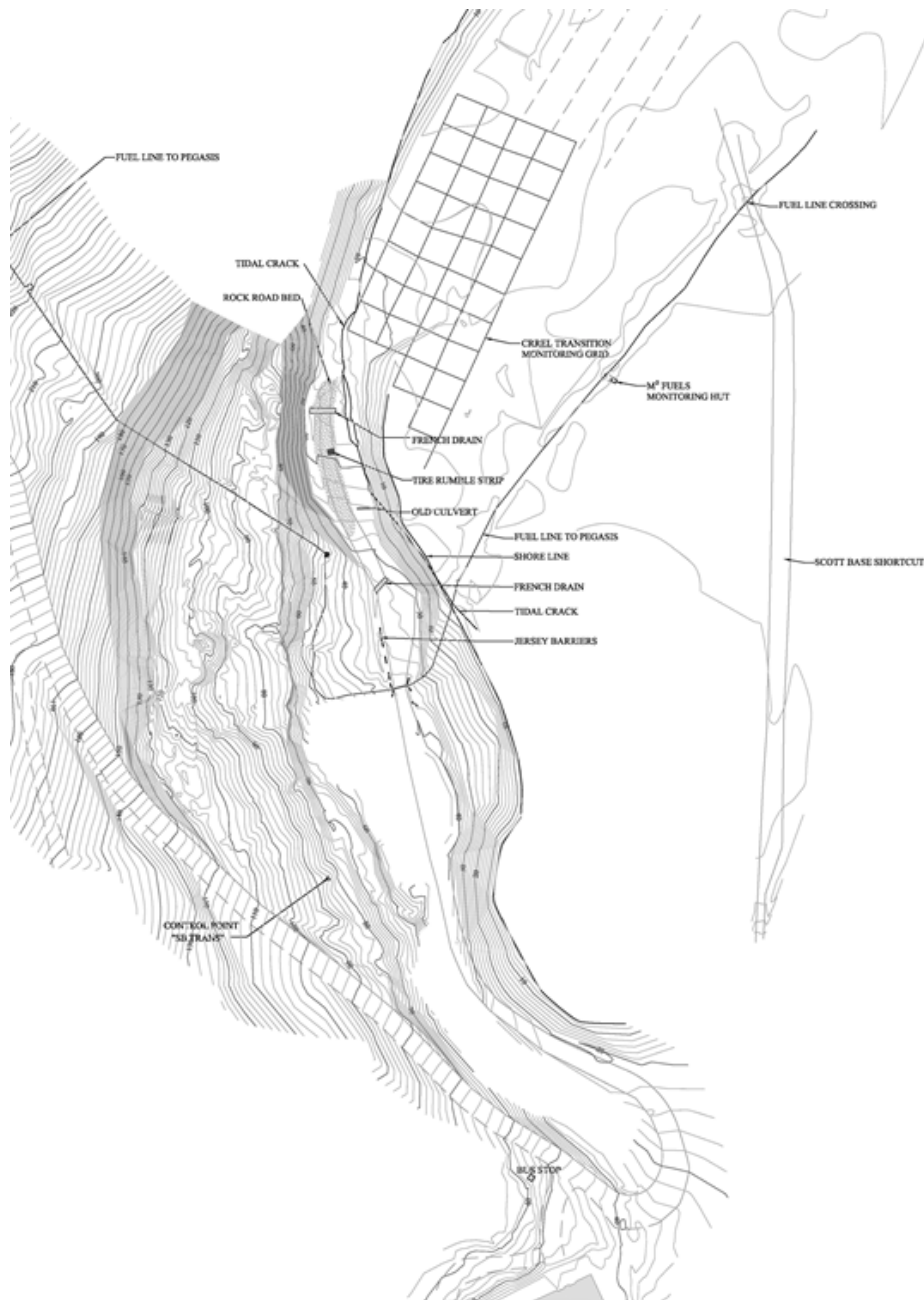
1. Drainage control—to keep water off the roads and the ice shelf.
2. Keeping the ice shelf clean—to keep dirt from vehicles off the ice shelf

The maintenance and construction descriptions below are grouped according to these objectives. Unless there is major road building or rebuilding, the Land Transition activities occur solely during Main Body season.

### **2.1 Drainage control on the Land Transition**

Keeping the road dry alleviates a variety of problems later on; water must be diverted from sheeting over or cutting under the Land Transition road surface. However, this must be done carefully as warm meltwater can undercut the subsurface of the road, causing sinking and erosion on the outer slope of the Land Transition road section. Many areas of the McMurdo road system, including the SBT, are composed of significant amounts of permafrost. If water is allowed to run across these portions of the road system, large cuts and chasms of ice melt and erosion will result. In addition, water and melting on the Land Transition results in mud, which invariably ends up on the vehicles and gets transported to the ice shelf. This must be avoided.

Figure 2. Map of the Scott Base Transition, showing the 2010–2011 placement of maintenance structures.



Installing and maintaining drainage structures can mitigate this problem by controlling the flow of water. One type of drainage structure is roadside ditches. Adequately sized and bermed ditches (Figure 3) will prevent water from flowing onto the roadway.

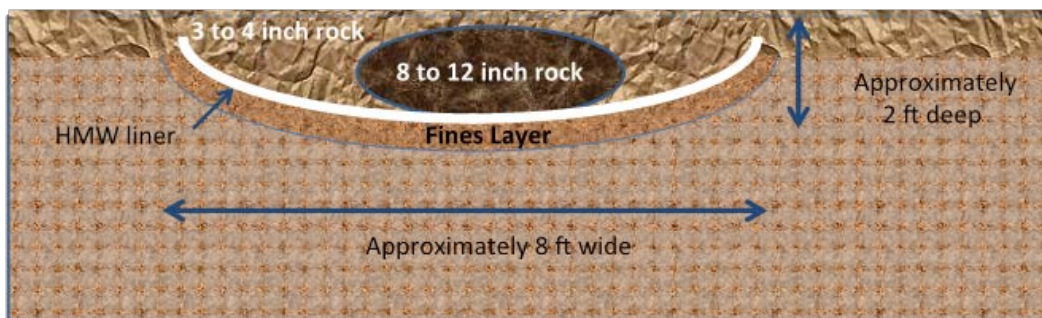
Figure 3. Upslope drainage ditches along the Land Transition of the SBT.



Further down slope toward the ice shelf requires an Antarctic French Drain (AFD) like the one shown schematically in Figure 4. An AFD consists of a ditch approximately 8 ft (2.4 m) wide and 2 ft (0.6 m) deep and is installed from the base of the rock cliff, across the road to the downslope outflow to allow water to flow from the cliff to the ice without causing erosion or wetting of the road surface. After initial excavation, lining the ditch with 3–4 in. (7.6–10.2 cm) of (gray) fines seals off the water from penetrating deeper into the road subgrade. Placing an impermeable liner on top of the fines-lined ditch will further channel the water. In 2010, 25 ft by 8 ft (7.6 m by 2.4 m) pieces of high molecular weight (HMW) plastic were used for the AFDs.



Figure 4. Schematic of the Antarctic French Drain.



There are varying qualities of red fines and gray fines on the McMurdo hillsides. The red fines are felsitic scoria and tend to be gathered from areas of lower ice content or less permafrost than the gray fines, which are vesicular basalt. This can give the impression that the red fines are more impermeable than the gray fines, but this is not necessarily the case. Both the red and gray fines are scraped from McMurdo area hillsides as “pit run” and screened to produce fines. It is important to excavate and screen fines carefully as one may otherwise end up with screened permafrost and ice clumps, which look like dirt or fines when relatively cold; but because of their high ice content, they become unstable and will melt and settle when they warm or contact water. More information on the McMurdo rock and fines can be found in Knuth and Melendy (2012).

Figure 5 illustrates how laying 8–12 in. (20.3–30.5 cm) rock on the plastic allows for non-erosive water drainage. The larger rock increases the drain’s lifespan and flow capacity over the 3–4 in. (7.6–10.2 cm) clean-off rock, which easily plugs with silt. Finally, clean-off rock (3–4 in. [7.6–10.2 cm] rock) should cover the plastic and the larger 8–12 in. (20.3–30.5 cm) rock to bring the ditch back to the normal road surface grade.

The plastic HMW liner should extend beyond the Land Transition road travel lanes on the downslope side to provide erosion protection for the roadside slope at the drain outlet (Figure 7). The side slope tends to crack and settle, and water runoff exacerbates the problem. Whether using a culvert or an AFD, it is imperative to ensure that the outflow is well past the road bed prism or unacceptable erosion and loss of roadway can occur. Two large rocks hold down the plastic for the outlet; the plastic does not need to be covered with smaller rock at the outlet as it is not part of the roadway.

This AFD successfully drains the water and prevents future subsidence and surface or subterranean erosion that is caused when inferior materials are used. Figures 5 and 6 show the 2010 construction, and Figure 7 shows close-up views of the inflow and outflow sides of a fully constructed, successful AFD.

Figure 5. The fines and plastic are installed, and the large rock is placed along the center of the drain.



Figure 6. The plastic sheet forms an outlet to protect the Land Transition's side slope from settlement and erosion.





Figure 7. The finished Antarctic drain inflow (top) and outflow (bottom).



Further up the Land Transition, toward Scott Base, the water crossing the road is a major factor in dirt being tracked out onto the ice. Previously,

small drainage ditches were cut across the Land Transition road. Traffic crossing these small ditches picked up mud. To fix this problem, transverse trenches 6–8 in. (15.2–20.3 cm) deep and 4 ft (1.2 m) wide were cut with a backhoe and then filled with 3–4 in. (7.6–10.2 cm) clean-off rock (Figures 8 and 9). Fines and HMW plastic are not needed here because the road subbase is solid, impermeable vesicular basalt with no permafrost and is not aggregate and soil over ice as previously discussed with the AFD construction.

Occasionally, plastic can be used at the roadside slope as a drain outlet to provide erosion control if necessary (as in Figure 7, bottom). In this case, the outlet should be cut deeper than the road trench, sealed with fines, and then laid over with plastic. The fines help prevent it from undercutting. Topping the plastic with large rocks as needed will help keep it in place. The location of these smaller drains should be determined by the location of heaviest flow across the road, which may change from year to year.

Figure 8. Unlined french drain crossing built with clean-off rock only.





Figure 9. Clean-off rock drain outflow without HWM plastic.



## 2.2 Keeping vehicle dirt off the ice shelf

A common issue carries from the Land Transition section onto the Ice Transition: dirt and mud tracked from the Land Transition surface out onto the ice and snow surface of the Ice Transition road reduces albedo and quickens the melt. Several strategies reduce the amount of dirt tracked onto the ice shelf:

1. Any vehicles using the ice shelf should be kept clean at one of the vehicle wash stations in McMurdo (Figure 10). This reduces the wear and tear on the vehicle and keeps dirt off the snow roads.
2. Dust and mud accumulated while driving the McMurdo–SBT Road should be removed at the pull-off vehicle cleaning station before driving onto the ice shelf (Figure 11). Cleaning stations should be maintained and stocked with appropriate tools for vehicle cleaning.

Figure 10. Using a vehicle wash station to keep vehicles clean and well maintained.



Figure 11. Vehicle cleaning station.





3. Approximately 100 ft (30.5 m) of 3–4 in. (7.6–10.2 cm) clean-off rock placed in a 6–8 in (15.2–20.3 cm) deep layer forms a clean road surface just prior to entering the ice shelf (see area of placement in Figures 2 and 12).
4. Shake plates provide additional vehicle cleaning. We recommend that 40 ft (12.2 m) of shake plate be used along the road (Figures 12 and 13). These plates are 8 ft by 10 ft (2.4 m by 3.0 m) and were originally made of 10 ft by 3 in. (3.0 m by 7.6 cm) angle iron welded in a pleated or corrugated shape. Light wheeled vehicles are required to cross the shake plates before going out onto the ice. Placing the plates near the start of the 100 ft (30.5 m) clean-off rock area but far enough to the right to allow Deltas and tracked vehicles to bypass around the plates (to avoid damage to the tracks or suspension of over-snow vehicles) greatly reduces the amount of dirt tracked onto the Ice Transition.

Figure 12. Shake plates and clean off rock help shake dust and mud off vehicles and keep them clean prior to entering the ice shelf.

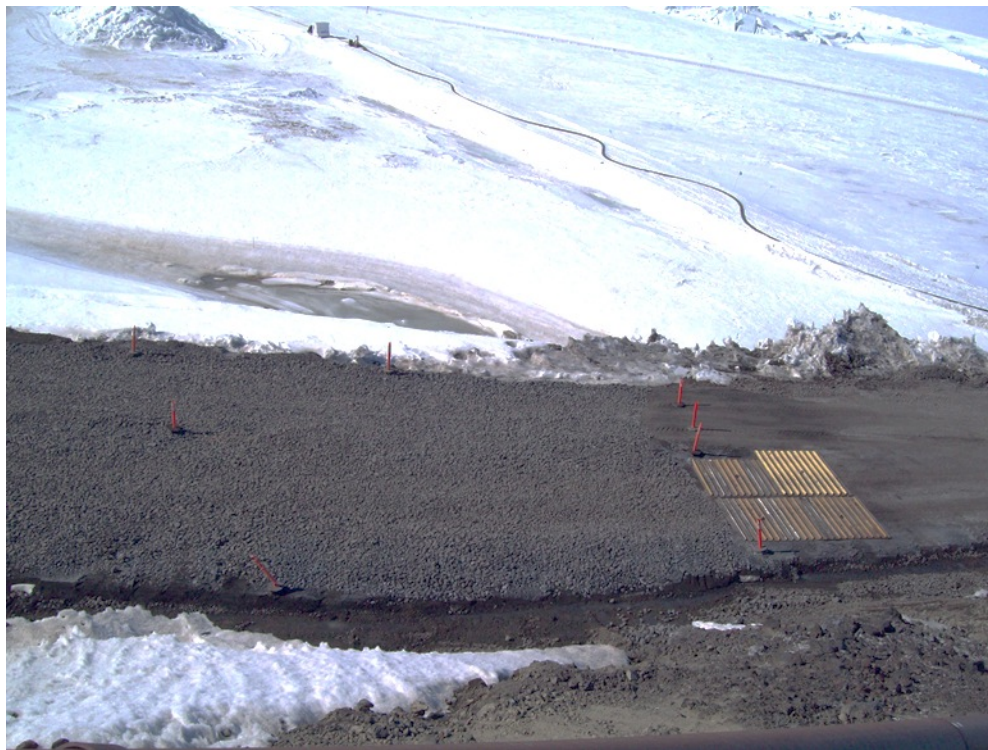


Figure 13. A U.S. Antarctic Program truck crosses the shake plates to clean off debris from the tires and body.





## 3 SBT Ice Transition

### 3.1 Seasonal maintenance

The ice shelf area of the SBT, referred to as the Ice Transition, has very different maintenance needs than the Land Transition. Not only does this section get solar input, dirt, mud, and a lot of vehicle traffic, but it also is damaged by water runoff from the cliff above. If not cared for, the Ice Transition will fail prematurely. The first and foremost requirement is to keep this section dewatered with appropriate water remediation and mitigation. It is also critical to ensure the cleanliness of the snow surface and to allow the least amount of traffic possible through the area. To do so, the maintenance of the Ice Transition is a year-round activity. The following subsections list the procedures required for the routine maintenance of the Ice Transition area during each season. Maintenance for specific problems should be used as needed. *Snow Road Construction and Maintenance Manual* (ASC, forthcoming) and Shoop et al. (forthcoming) provide additional information on typical snow-road construction, maintenance, and repair.

#### 3.1.1 Winter tasks

The following tasks maintain the snow surfaces over the winter season to allow for easy opening of the roads for Winfly.

1. Bring the snow-road grade to a smooth, gradual incline to the rock road. Fill low spots by using 4–6 in (10.2–15.2 cm) thick compacted snow layers (lifts).
2. Cut through rollers (pressure ridges formed parallel to the Scott Base shoreline and perpendicular to glacial ice motion); and push excess snow into two stockpiles, one on either side of the road, for use during the summer. Encourage drifting snow to accumulate in this entire area for use in the summer.
- 3.

4. Figure 14 shows the rollers and snow stockpiles.
5. Goose or drag snow once per month to keep the area level and smooth.
6. After storms, goose or drag and compact snow to build smooth, level layers (lifts) of compacted snow. This will help the transition last through the melt season.

### 3.1.2 Winfly tasks

Full construction of the Ice Transition begins during Winfly. Compact the road with a sheepsfoot roller once per month. Goose and drag as needed.

### 3.1.3 Main Body tasks

The activities needed to maintain the Ice Transition during the Main Body research season are more numerous than for the Land Transition and are covered in detail in the remainder of this chapter. The most important task in maintaining the Ice Transition segment of the SBT is to keep the snow albedo high (keep snow white). This reduces roadway and road-base disintegration (i.e., snow decomposition and melt).

This is accomplished by the following measures, which are important to implement early in the season to optimize road performance during melt:

1. Remove meltwater as quickly as possible. **This is critical.** Liquid water causes a large reduction in albedo, creating a vicious cycle of melting, further decreasing of albedo, and then further melt until the water is removed. A delay in removing any meltwater only causes further deterioration of the area and increases the amount of work needed later.
2. Keep the snow clean.
3. Keep the snow packed.
4. Keep the snow smooth.
5. Use stockpiled snow to fill ablating areas and to keep the snow white (high albedo).

Methods of attaining the above goals may include the steps listed below:

1. Excavate a ditch to drain cliff runoff.
2. Drill holes to drain the cliff runoff pond.
3. Take photos of the area to determine a dewatering plan for the ice shelf.
4. Ditch as needed to consolidate ponding areas.
5. Drill holes to drain retention and infiltration ponds.
6. Remove and stockpile saturated snow from the Ice Transition surface.
7. Repair, rebuild, and patch the Ice Transition road.
8. Complete ditching to ensure drainage of the Ice Transition area.

Figure 14 shows images of the progression of the SBT during the melt season from December 2010 to January 2011. The image on the left shows the stockpiled snow and all four lanes of the snow road in excellent condition (at the opening of the snow roads to Pegasus). The center image was taken on 25 December 2010 and clearly shows the dark color and decreased albedo of the melt pools. The image on the right, taken on 17 January 2011, shows the decreased stockpiles of snow, the water collected in the drains near the cliff face (left side of the image), the decreased size of the melt pools (through drainage holes), and the repaired lanes beginning to heal although melt is still visible.

For comparison, Figure 15 shows the same area from 8 January to 28 February 2014. The conditions were clearly quite different between the two years. During 2014, the ice shelf broke out in front of Scott Base and close to the snow road at the transition area. The differences in Figures 14 and 15 illustrate how widely varied the conditions can be.

Many of the following construction and maintenance elements can be seen in these images:

- The four traffic lanes on the ice-shelf chute

- The stockpiles of snow on either side of the road
- The cliff-face drainage ditch to collect the meltwater and to keep it from going onto the road
- The rollers that are cut back during winter
- The drainage pools forming near Scott Base Shortcut Road during melt season

Figure 14. Images showing the SBT Ice Shelf through the progression of the melt season. The dark areas on the ice shelf are meltwater pools and wet snow (6 December 2010 to 17 January 2011).

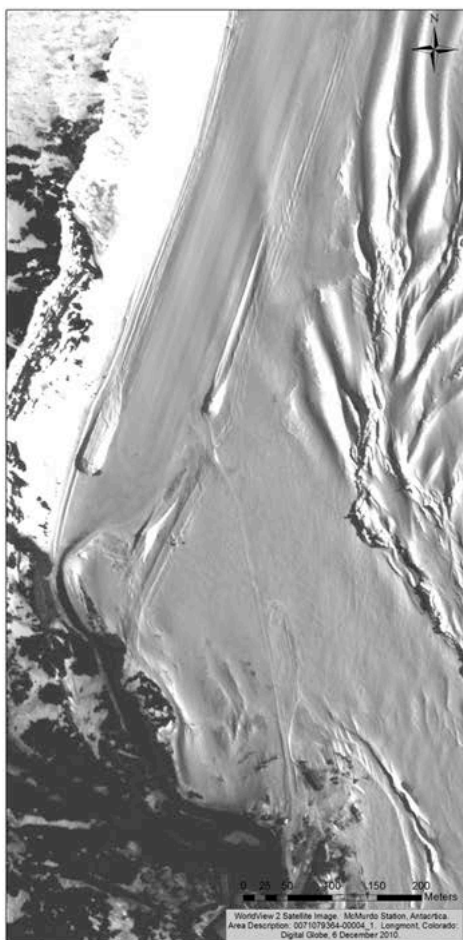


Image Aquired on 6 December 2010

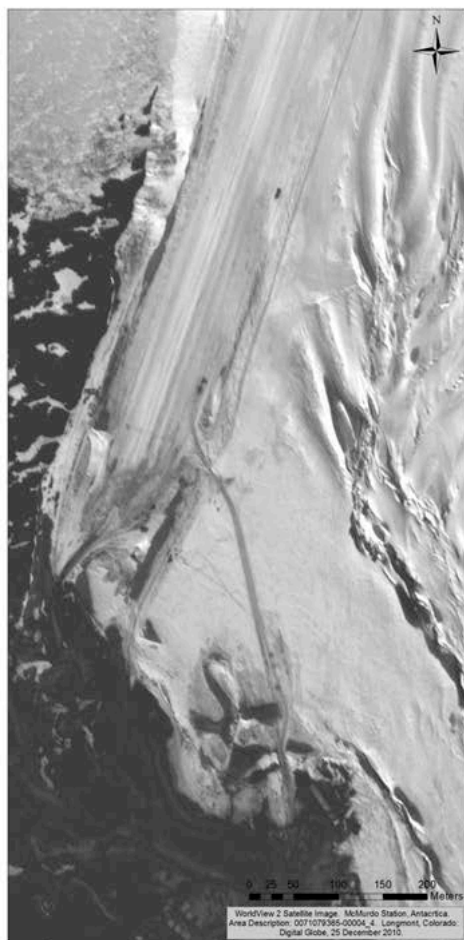


Image Aquired on 25 December 2010

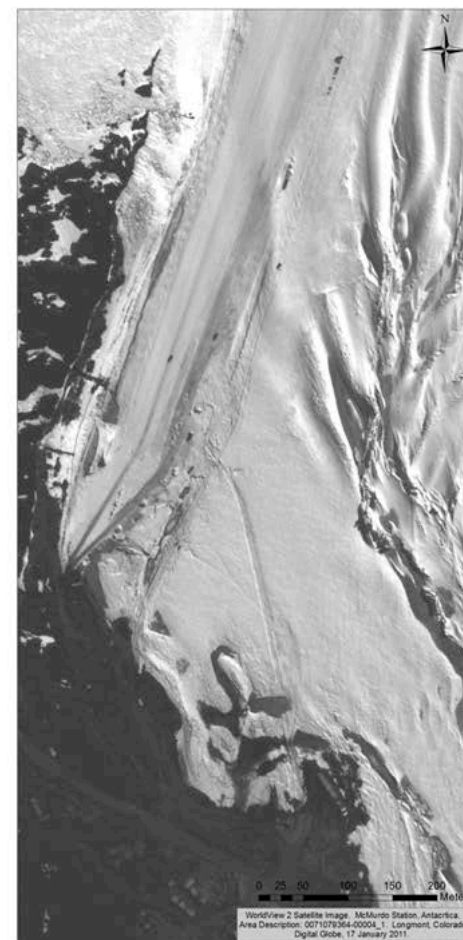
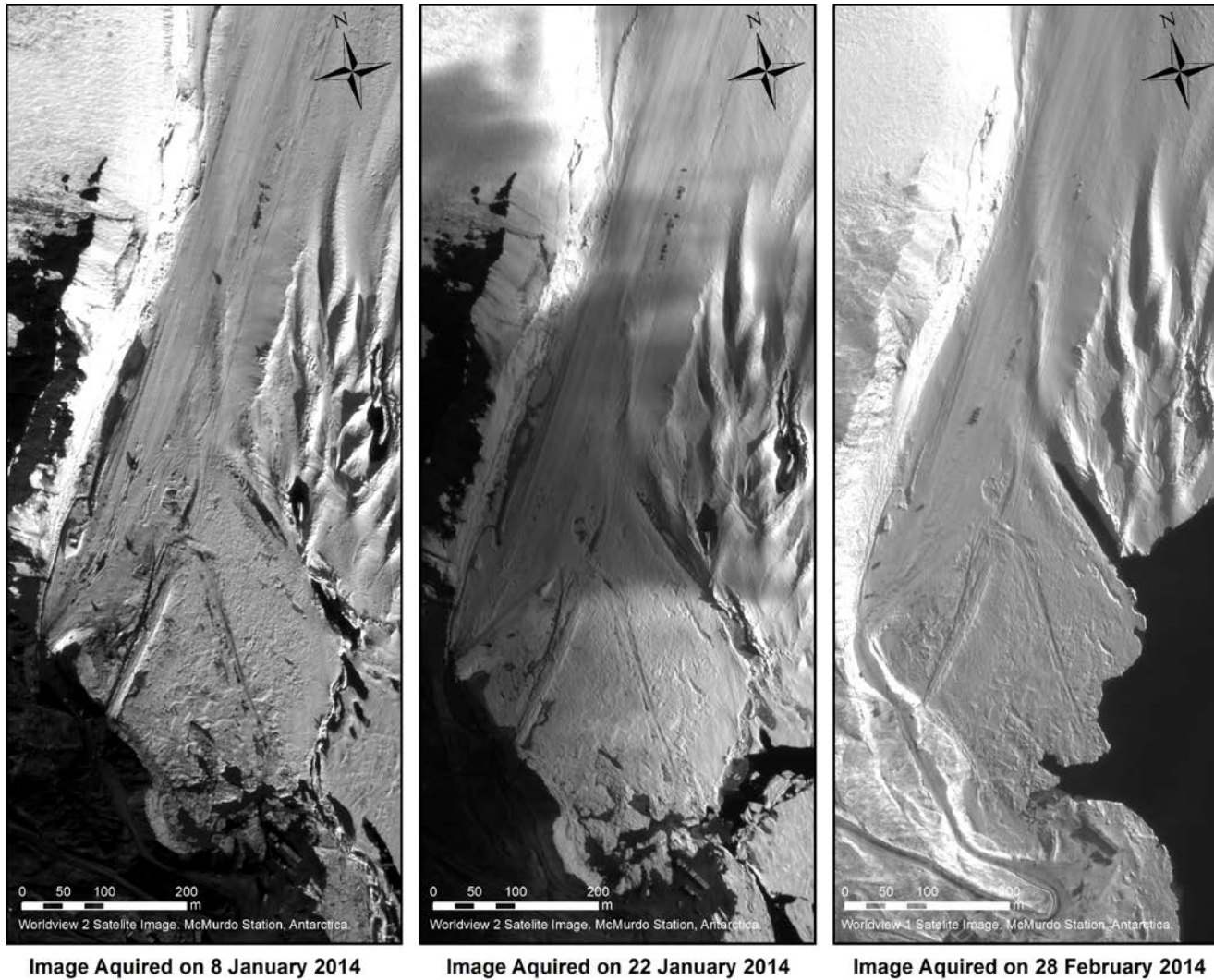


Image Aquired on 17 January 2011

Figure 15. Images showing the SBT Ice Shelf through the progression of the melt season and ice shelf breakout. The dark areas on the ice shelf are meltwater pools, with open water shown on the right-hand side by the end of the season (8 January to 28 February 2014).





### 3.2 Catchment for the cliff meltwater

The water runoff from snow melting on top of the cliff (Figures 15 and 17) is another aspect of water mitigation. In some past seasons, a ditch was cut along the bottom of the cliff; and it flowed to a runoff catch basin or retention pond. This drainage kept water from flowing onto the Ice Transition area. Cutting the ditches deeper may entail digging the catch basin deeper. A laser level or the survey department should determine the slope line and the depth of the ditch's excavation. This ditch could be cut with a D4 (a small bulldozer) or a backhoe. An excavator would be best suited for this project, if available.

Figure 16. Water runoff down the cliff face.



Figure 17. Drainage ditch to catch cliff meltwater.



### 3.3 Dewatering the ice shelf

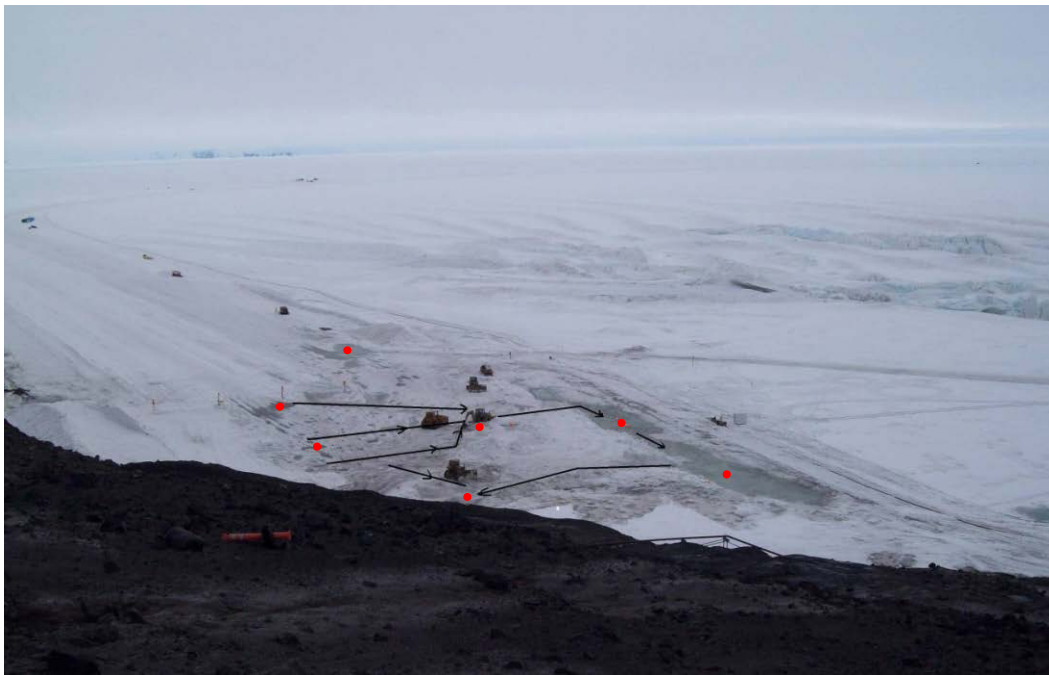
Once the Ice Transition starts to deteriorate, a dewatering scheme should commence. Because the dewatering plan can change drastically from year to year, it can be helpful to take photos from the adjacent cliff to sketch out the water flow pathways and where the drainage holes should be located. In the 2010–2011 example in Figure 18, the water flow lines are in black, showing the direction with arrows; and the drainage points are red dots.

While drilling the holes once implementation of the plan begins, a backhoe should start digging trenches from the drainage points back toward the cliff side because even after the melt pools are drained, there is still water flow coming from the cliffs. Throughout this process, two compacted snow lanes next to the cliff should remain open for traffic while the main transition is reconstructed. In locations where there is heavy traffic and ditching is not possible, a trash pump and hose can be effective for dewatering.

The drainage in the Ice Transition area is different every year, so the mitigation strategy must be adaptable and planned according to the situation at hand.



Figure 18. An Ice Transition photo from the cliff. The water flow lines are in black, showing the direction with arrows, and the drainage points are red dots.



### 3.4 Draining the retention ponds

In 2010–2011, two large ponds formed between the Ice Transition and Scott Base. A ditch was trenched from the big ponds to the low area by the Land Transition, forming a single new retention and infiltration pond. During that season, in the new pond that formed at this low point near the fuel line side of the transition, nine holes were drilled 28–30 ft (8.5–9.1 m) deep with a hot water drill (Figure 19). In this case, most of the holes took 15 minutes to drill. After punching through the ice, hitting a crack or void, the water began to drain quickly. It took about a day and a half for the big pond to drain to approximately 20% of its original capacity. Any drill holes and ditches should be located and recorded with GPS and kept on file with the McMurdo survey office. Recording the drill-hole locations and depths over the years provides insight into the structure and behavior of the ice shelf in this area.

Figure 19. Hot water drilling to drain the retention ponds.

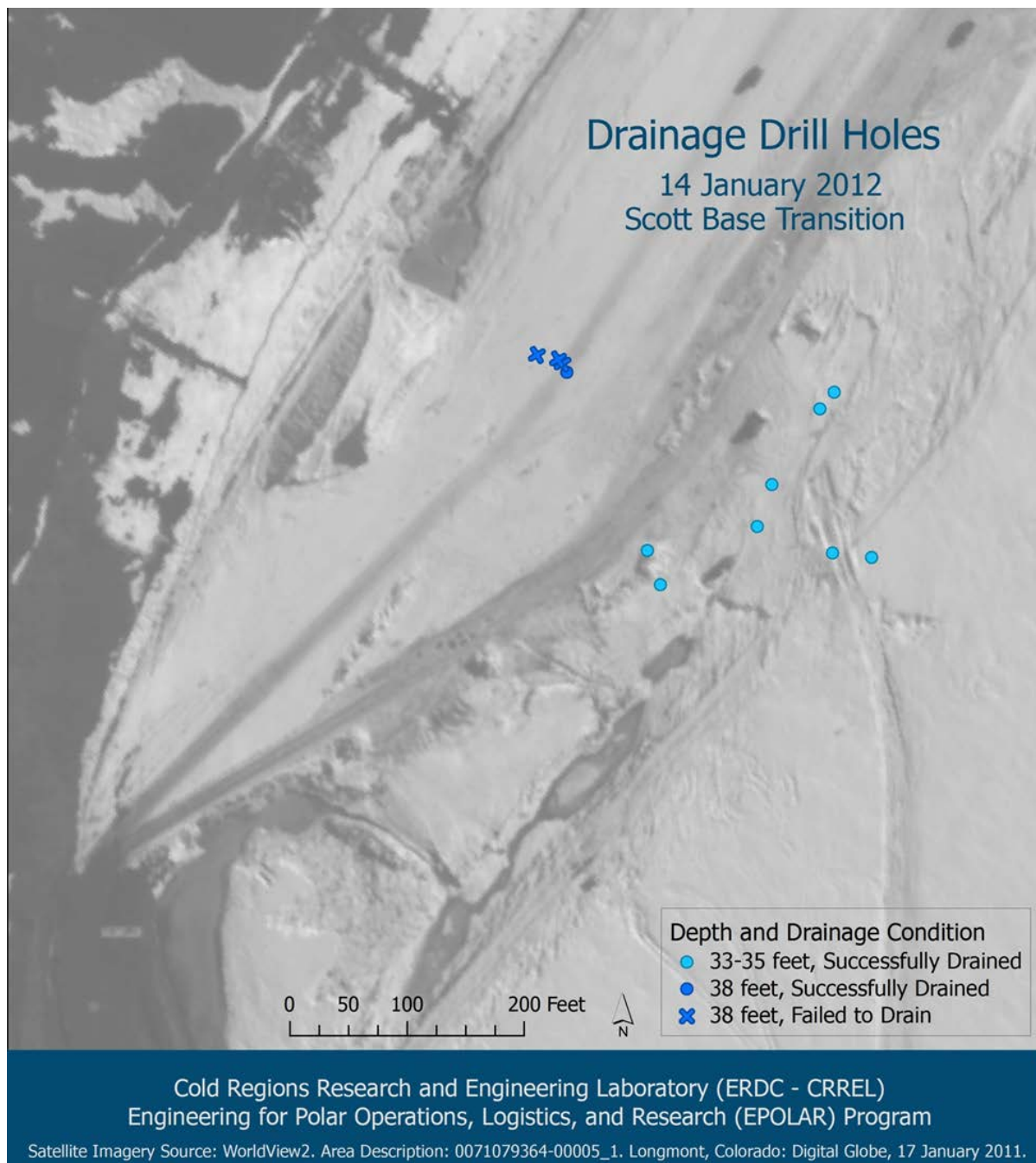


In 2009, a ground-penetrating radar (GPR) survey of the Ice Transition area indicated it is likely underlain by fractured ice within which a drainage network exists, possibly reopened every year by ice flow against the land (Arcone and Bjella 2009). The study recommended drilling several holes for drainage and placing them in different locations each year. Multiple holes would better access the drainage network within the fractured ice. The holes should be at least 26.3 ft (8 m) deep but preferably around 39.4 ft (12 m).

Figure 20 shows the location of the drill holes from January 2012 (33–38 ft deep [10.1–11.6 m]) overlain onto earlier imagery. The uniformity in the depth of successfully drained holes (33–35 ft [10.1–10.7 m]) suggests that drainage may have been into the seawater below the ice shelf instead of into a fracture system. The grouping of holes closest to the cliff was 38 ft (11.6 m) deep, and all but the furthest seaward hole encountered sediment (presumably the sea floor or the under-ice continuation of the cliff). At this time, the exact mechanism and subsurface drainage pathways on the Ice Transition are unknown.

Once drilled, these areas usually stay functional through the latter part of the season.

Figure 20. Drill sites for drainage holes from January 2012.



### 3.5 Ice Transition road maintenance during the melt period

While dewatering is underway, the wheeled and tracked vehicle lanes need to be rebuilt and opened. The track lane area (usually on the far right side of the road, outbound) attains the highest density road base due to compaction by cargo and heavy vehicle use. This lane often weathers the initial melt season better than the other lanes because this compacted (ice) base

can still support heavy vehicle traffic. Eventually, the additional traffic and excessive meltwater cause potholes to form; and the impermeable ice layer prevents drainage so that these lanes will also need repair. Figure 21 shows the beginning of this process during the 2010–2011 season. Once the tire lane is dewatered, it should be covered with a thick lift of new snow, about 2–3 ft (0.61–0.91 m) thick. This should be track packed with a D-7 dozer; back dragged with the blade; and then dragged smooth with a drag, goose, or SnowPaver. Depending on the season, the exact timeframe of this critical period will vary; and environmental conditions may facilitate freezing solid overnight, or it may stay warm, causing a continued struggle. Once it freezes, it will stay in good shape until the end of the season and can be maintained using the Challengers and normal snow-road techniques.

Figure 21. First lanes to be rebuilt and reopened to traffic during the 2010–2011 season.

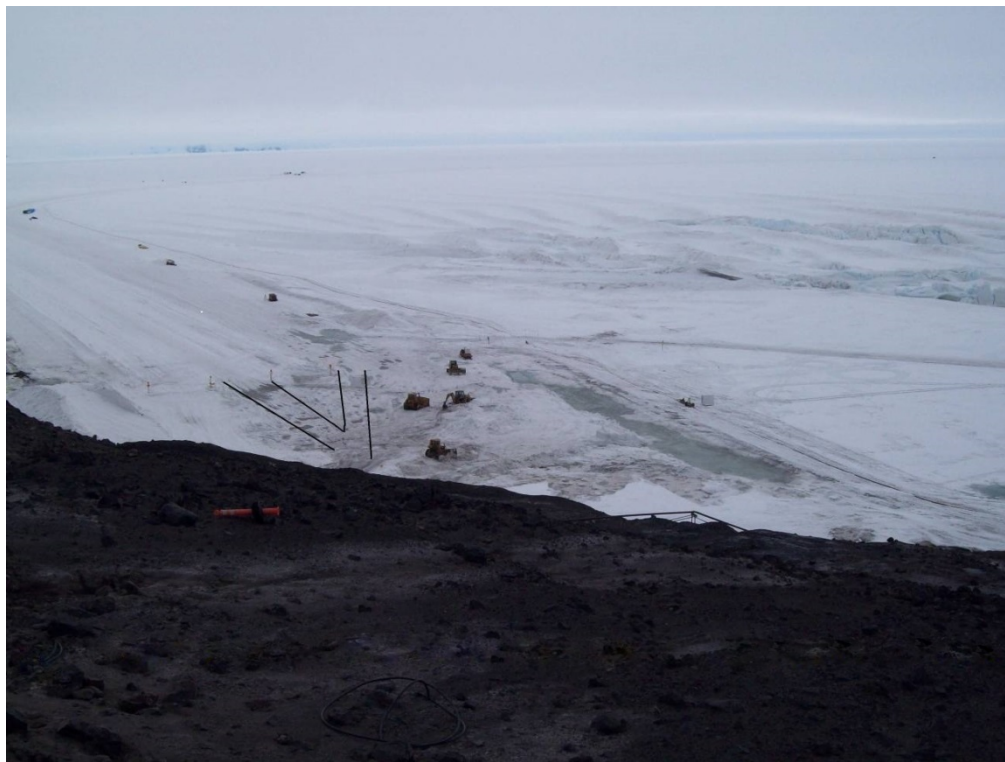


Figure 22 shows the reconstruction of the Ice Transition as the first two lanes were worked and the rest of the area was being dewatered. Once these lanes were 100% completed, the rest of the transition was rebuilt.



Figure 22. Continued construction during the 2010–2011 season.



Once the first two lanes are established, the remaining Ice Transition area may need to be scraped to the ice to remove the saturated snow and to fix melt pools. Figure 23 shows the general conditions of the Ice Transition from dirty vehicles, solar impact, and migrating water while Figure 24 shows melt pools and potholes prior to the Ice Transition being dozed. The excavated material is stockpiled outside of the travel area to allow it to drain. After draining the frozen slush, this material is mixed with clean snow and provides good patching material for holes on the Ice Transition surface, much the same way as repairing asphalt on a highway. This mixture may be used for filling in the large areas that have been dewatered, for filling in the dewatering ditches after draining, and as a subbase for the new lanes.

Figure 23. General conditions in the Ice Transition prior to maintenance.

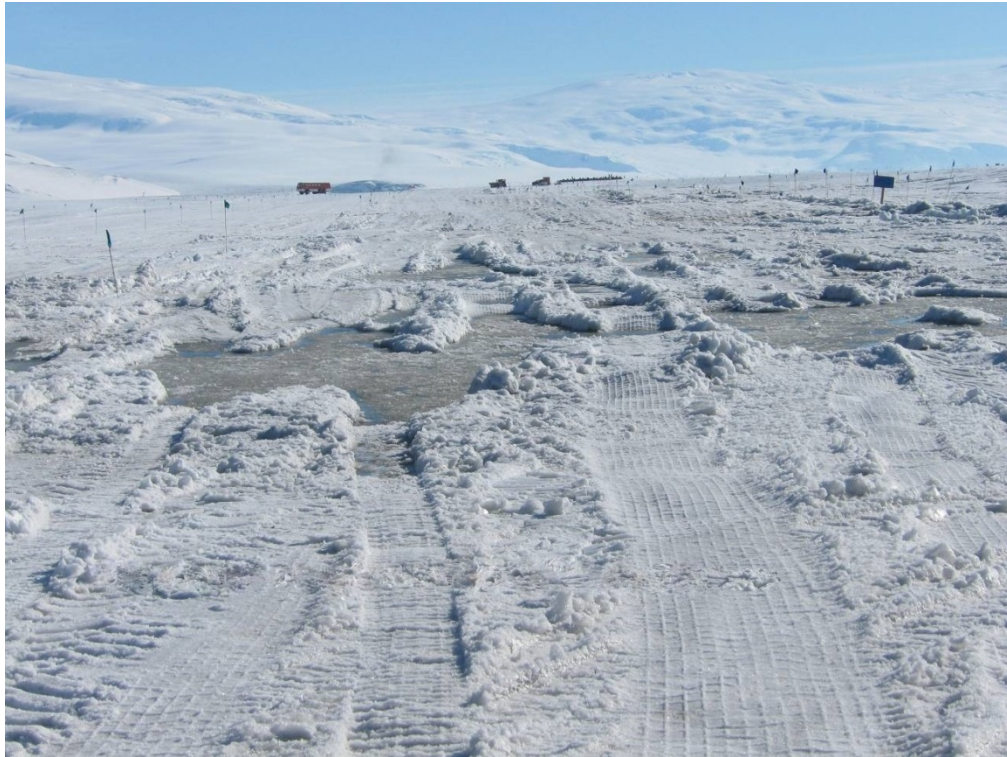


Figure 24. Melt pools requiring maintenance on the Ice Transition.



During this time of clearing and filling melt pools, a ripper helps to break up any ice layers that have formed below the road bed as a result of repeated freeze–thaw (Figure 25). This layer is particularly common on the track vehicle lane where the heavy cargo vehicles compact the snow. These ice layers block the melting snow from percolating downward into the firm. Once the ice layer is broken, mixed, and compacted, additional clean, stockpiled snow can be used to increase the height of the patch. It is ideal to create a patch that is a mix of the colder ice from below and the warmer surface snow, with the patch being above grade by 1–2 ft (0.3–0.6 m). The patch will solidify during the Antarctic summer “nights” when the temperatures drop slightly, and it can be graded level after a couple of days.

Any new holes that appear may require digging out, ripping, and patching with the snow and slush slurry mixture as needed (Figure 25). The new lanes and patched areas can be covered and rolled with new or stockpiled clean snow as available. As discussed by Shoop et al. (2013, 2014), in 2011 and 2012, the clean snow was laid down on the lanes by a Challenger pulling a snow milling machine (the Keweenaw Research Center SnowPaver), which mixed and compacted the road (Figure 26).

Figure 25. Scraping, ripping, and patching the rest of the Ice Transition after stabilizing the primary lanes.





Figure 26. The Keweenaw Research Center SnowPaver mixes and compacts the wet snow at the SBT (January 2012).





## 4 Conclusions

Keeping the dirt and debris off the ice is essential for having a solid, well-built Ice Transition roadway section. A properly maintained Land Transition is key to ensuring a clean ice shelf to minimize melting. The final result is a well maintained SBT area that is passable through the melt season (Figures 27 through 30). The melt pools are under control and lanes are open.

Additionally, the condition of the SBT depends on the weather and snow, which change drastically from year to year. The success of keeping the SBT operational depends on the preparedness of the area and on the training, ingenuity, and teamwork of the fleet operations crew (Figure 31). The information in this report serves to assist the fleet operations personnel with guidelines but by no means covers all of the possible issues and potential solutions.

Figure 27. The SBT Ice Shelf area 29 December 2011.



Figure 28. The SBT Ice Shelf area 13 January 2012.



Figure 29. 2010–2011 season prior to Ice Transition meltwater mitigation.





Figure 30. Final results—a nice dry and passable Ice Transition.



Figure 31. Discussing techniques to fix the melt pools.



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